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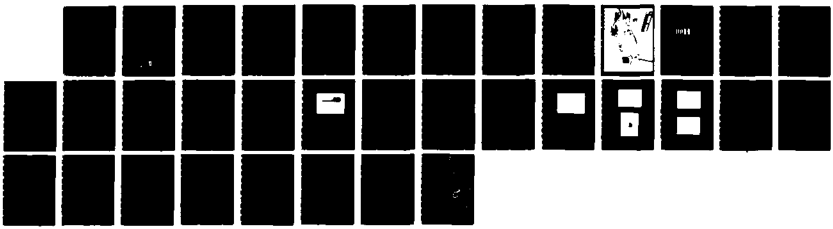

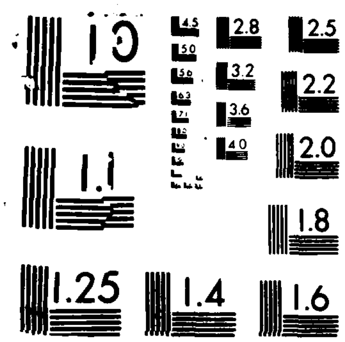
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Holographic Interferometry was attempted as a means of monitoring surface erosion and rejected because of large signal-to-noise problems. A new type of common path diffuse point interferometer has been developed to profile (electrode) surfaces. Initial studies show that the stability of this interferometer is at least two orders of magnitude better than what has been seen with standard Michelson's interferometer. Some measurements carried out with this interferometer are reported here.

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SUMMARY

Holographic Interferometry was attempted as a means of monitoring surface erosion and rejected because of large signal-to-noise ratio problems. A new type of common path diffuse point interferometer has been developed to profile (electrode) surfaces. Initial studies show that the stability of this interferometer is at least two orders of magnitude better than what has been seen with standard Michelson's interferometer. Some measurements carried out with this interferometer are reported here.

1.0 WORK STATEMENT AND PROGRAM OBJECTIVES

1.1 Statement of the Problem

Material erosion at high temperatures occurs in various space and missile propulsion systems. For example, magnetoplasmadynamic (MPD) thruster electrodes erode during operation in high temperature plasma environments. Rocket engine nozzles also are subjected to erosive environments by particle laden combustion gases existing in the combustion chamber. Adequate methods for measuring erosion recession in hostile environments are not available to support development testing of propulsion systems. Some components of interest in space applications are required to have long lifetimes (f10,000 hours or greater). Practical testing of such components require extremely sensitive methods to reduce test times to useful lengths. Present methods used to measure erosion recession include radioactive tracing and quartz crystal microbalances. Both measurements are indirect insofar as they measure loss of mass rather than change in dimension and shape. They are also only used at specific points because they must be implanted into the surface of the material.

Thus, a direct measurement of the shape of the eroding material with sufficiently high resolution would present significant advantages, particularly if it could be used to measure a complete surface rather than a few specific points. The research that is being conducted under this program is anticipated to provide a fundamental understanding necessary for making such measurements with optical techniques.

1.2 Program Objective and Achievement

The aim of this research program is to investigate the possibilities of developing a non-contact optical technique by which surface erosion resulting from exposures to a high temperature plasma environment can be monitored and measured. Three approaches; viz.,

a. Astigmatic Ranging Probe (ARP)

b. Holographic Interferometry (HI)

c. Diffuse Point Interferometry (DPI)

were considered to have the potential to evolve into surface monitoring devices. However, early in the program it was realized that the ARP technique when applied to a rough surface was beset with serious signal-to-noise problems and, hence, was discarded.

As mentioned in the first annual report[1], a good part of the first year was spent developing the DPI technique and the preliminary results indicate that it can be a viable surface analysis tool.[1] In the second year of this program, we looked at the applicability of holographic interferometry to surface erosion as well as ways to ruggedize the DPI. The study on the former was carried out during the period April - September 1986, and that on the latter between October 1986 and March 1987. The results and conclusions of these studies are presented here.

2.0 RESEARCH EFFORTS

In this section, we discuss in detail the results of HI studies done on eroded surfaces and the development of a new type of common path DPI.

2.1 Holographic Interferometry

A schematic diagram of the holographic interferometry set up is shown in Figure 1a, and the photograph of the set up is shown in Figure 1b. A hologram of an object is recorded by interfering the object wave and reference wave on a recording medium such as a photographic or thermoplastic plate. Upon illuminating the developed plate with the reference wave, an image of the object appears at the exact location of the original object. This process is called holographic reconstruction. If the object is illuminated at the time of reconstruction, interference between the object wave and the reconstructed image wave will occur. This type of interferometry is referred to as real time holographic interferometry. The resulting fringe pattern depends upon the state of the object after the initial hologram has been recorded. From the fringe pattern, information about the final state of the object can be inferred. For example, when an object such as a bar held firmly at one end is displaced at the other, it gives rise to interference pattern as shown in Figure 2b. The displacement, z, undergone by the bar at a certain point is given by $z = N\lambda/2$. where N is the order of the fringe at the position where the displacement is z. N is counted from the bright fringe on the bar that corresponds to zero

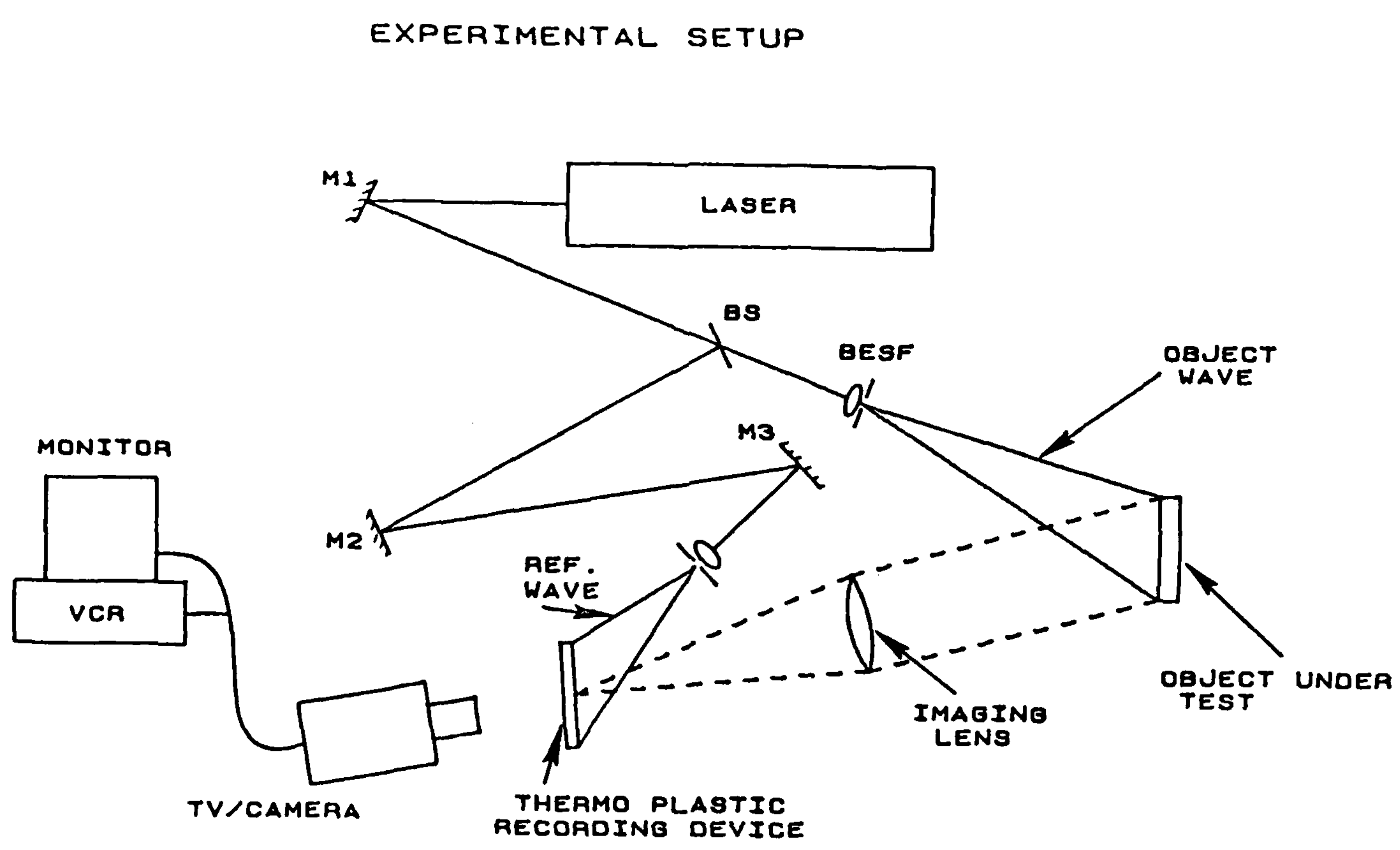

Figure 1a. Schematic Representation of the Holography Setup

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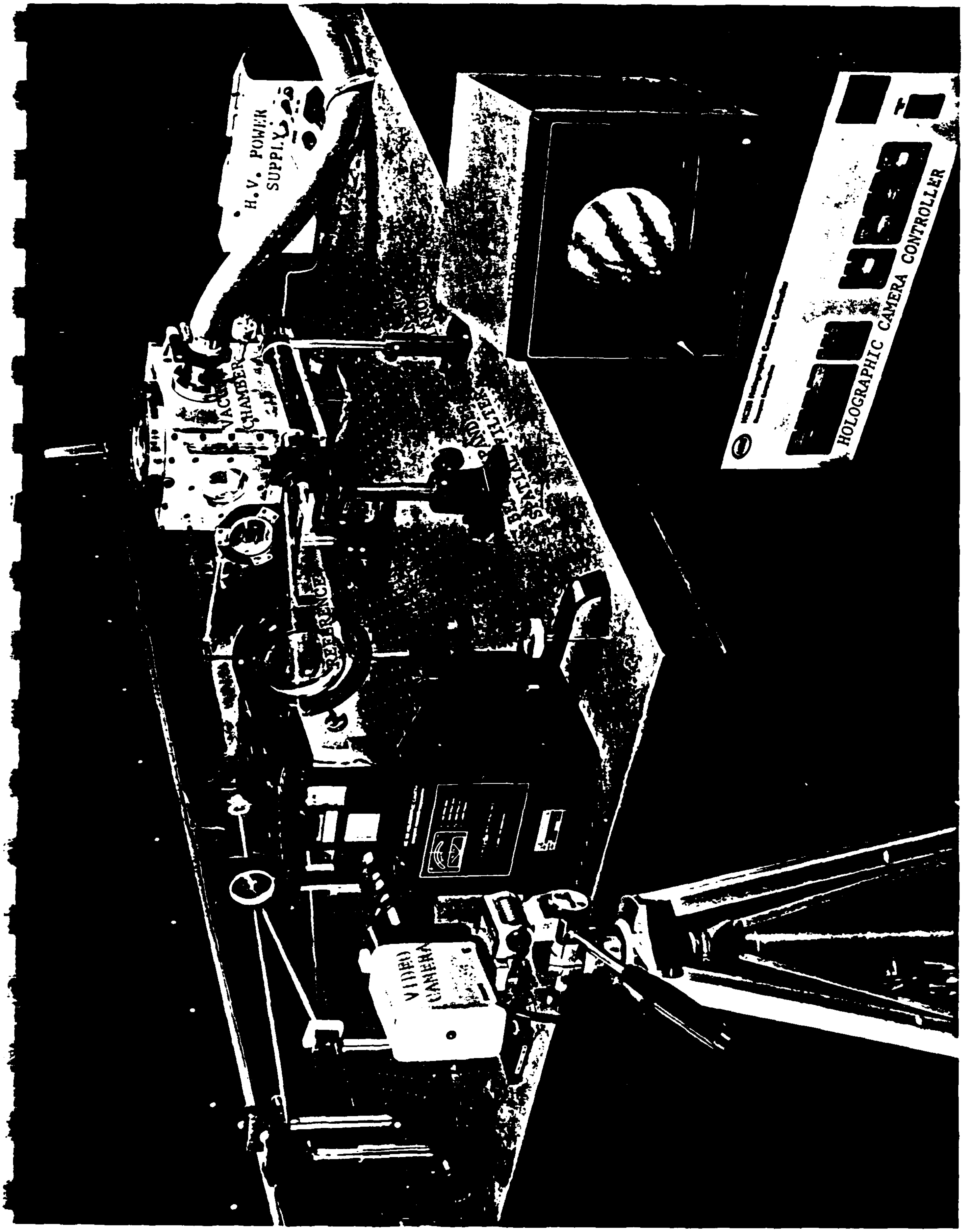


Figure 1b. Holography Setup

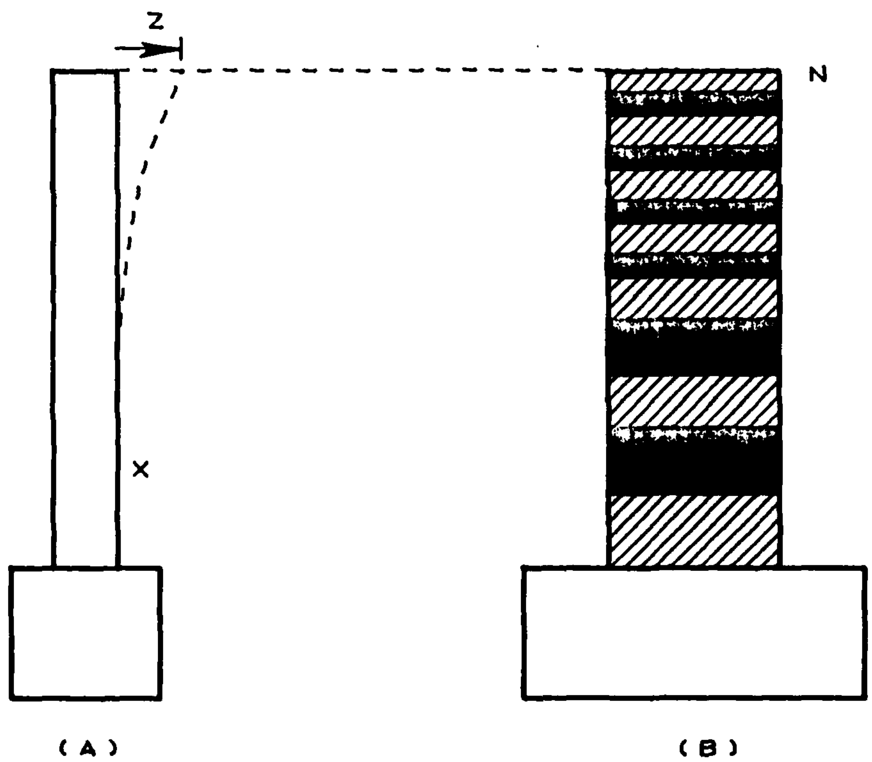


Figure 2a. Side View of the Bar Under Going Displacement.

Figure 2b. Fringe Pattern Seen on the Front of the Bar.

displacement. Similarly, other rigid body motions can also be detected, with respect to a reference point, using holographic interferometry.

Attempts were made by us to use this concept to monitor the erosion on a copper electrode surface resulting from an electrical discharge. In this regard, real time holographic interferometry was tried. A hologram of the electrode was recorded before the electrical discharge was struck and superposition of the reconstructed image on the object gave rise to an infinite fringe pattern. Next, a discharge was struck between the electrodes under dynamic flow conditions as discussed in the last report.[1] The plasma current was maintained at 1.2 mA to avoid unwanted thermal problems because it was found earlier that the electrode temperature when taken beyond 70° C and cooled back to the ambient temperature, resulted in a finite fringe system on the electrode surface instead of the original infinite system. This indicated that the electrode did not return to its original state. At a discharge current of 1.2 mA sustained for two or more hours, the temperature rose to and stayed at 55° C. At this temperature it was found that the electrode did return to its original state upon cooling to room temperature.

Because of the dynamic flow condition, the vacuum chamber was constantly being subjected to some amount of vibration. Starting with an infinite fringe system, this vibration over a 16 hour period generated two fringes over the face of the electrode. As a first approximation, one can consider these fringes as background noise and subract them from the interferogram that results after the surface erosion. However, no surface erosion could be detected with HI if a low discharge current was maintained for only a few hours.

To compensate for the lack of measurable surface erosion, it was decided to increase the discharge period to 16 hours. Holographic Interferometry carried out at the end of this period revealed the presence of two fringes after background subtraction. Presence of a finite fringe system indicated that the surface motion can be caused by a combination of erosion and displacement gradient. Thus, it was found that both situations; viz., high discharge current - short discharge period and low discharge current - extended periods of discharge did result in surface motion other than linear displacement. Hence, one has to subtract the contribution from displacement gradient in order to arrive at linear displacement due to surface erosion.

2.2 Sandwich Holography

In order to remove unwanted fringes, a type of holography called sandwich holography can be employed. This approach devised by Abramson[2] can be utilized to remove interference fringes generated by unwanted motion of the object between holographic exposures. See Figure 3. Two photographic plates A & B kept in tandem in a plate holder with the emulsion sides toward the object are exposed to the object in its initial unstressed state (Figure 3a). A second pair of plates C & D are next positioned in the holder and another exposure made after the object has been stressed (Figure 3b). After the plates are developed, a sandwich hologram is made by combining A and D, or B and C and illuminating the plates with the reference wave (Figure 3c). When the two plates are properly repositioned in the plate holder, no interference fringes should be seen on the undeformed surface. If any are seen, it means

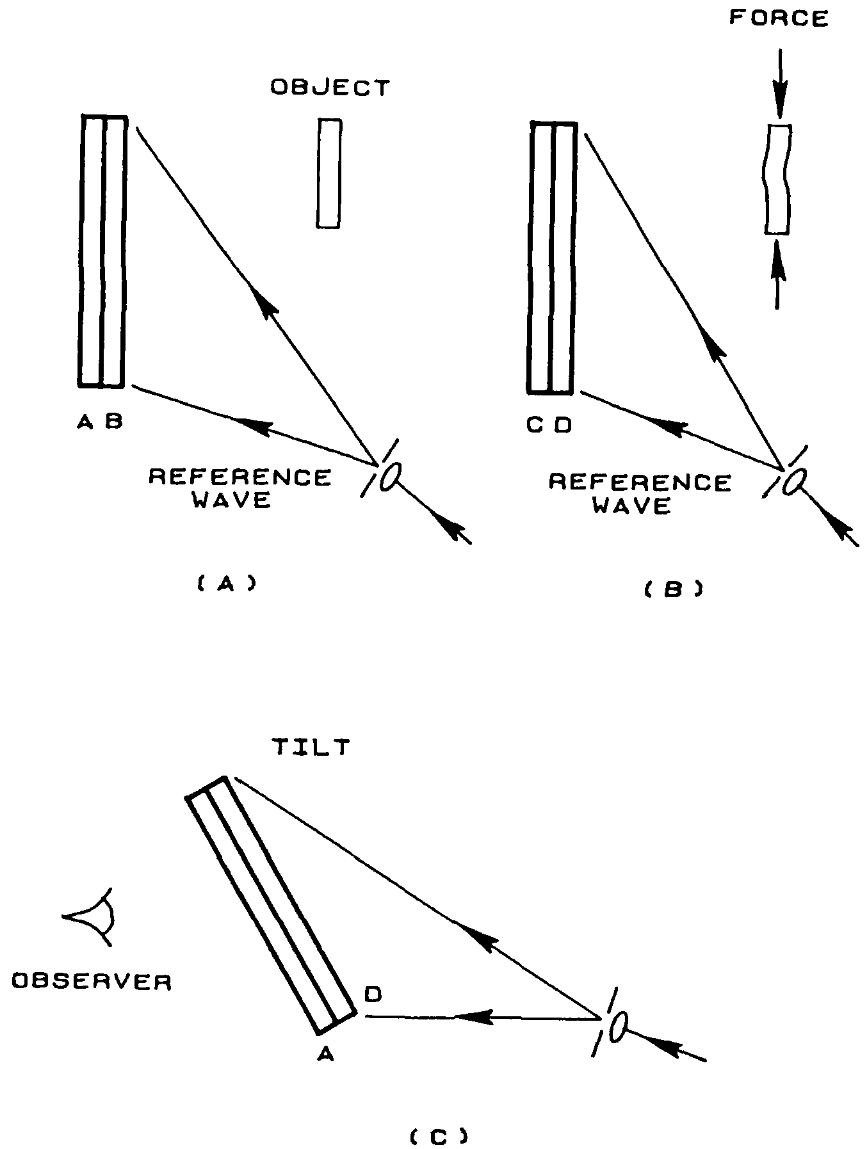


Figure 3. The Three Steps Involved in Producing a Sandwich Hologram are Shown Here.

that the object has undergone rigid body motion between exposures. By manipulating the sandwiched plates, one can readily get rid of the unwanted fringes and the fringes that remain are those due to the actual deformation of the object. These fringes can also be compensated for by providing proper tilt, rotation and translation to the sandwich plates. Knowing the magnitude of these motions, one can calculate the deformation undergone by the object.

If this type of holography can be implemented in our study, then unwanted motion of the electrode due to thermal and mechanical perturbations can be accommodated. To achieve this requires a reference surface to be placed on the electrode itself or in close proximity of the electrode. For the latter situation, the case in our study, the reference surface should be capable of responding to extraneous perturbations like the electrode surface would. Hence, the reference surface should be made of the same material as the electrode.

In this study, a copper collar attached to the electrode, as shown schematically in Figure 4, was used as the reference surface. Since the collar is in contact with the electrode, the two can be at the same temperature. This is ideal for subtracting fringes due to spurious thermal perturbation. However, with the copper collar in place, we found that it was very difficult to maintain a uniform and stable discharge even at low discharge currents. Hence, we have abandoned this concept as well.

Because of the numerous limitation and constraints found in using holography for this purpose, we concluded that it is not likely to be tractable to the real test conditions required to monitor surface erosions in electrical propulsion.

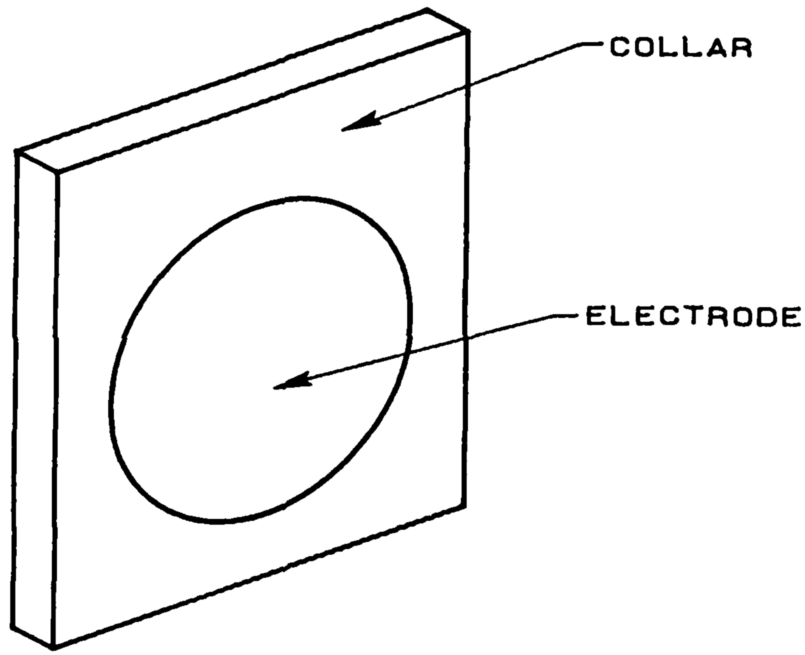


Figure 4. Schematic Representation of the Electrode and the Reference Surface (Collar).

3.0 DIFFUSE POINT INTERFEROMETER

The principle of operation of the interferometer was reported in the first annual technical report (SDL No. 86-2439-03).[1] The last six months in the second year of the program was spent looking at ways to ruggedize the interferometer. It is our aim that the interferometer be insensitive to the kind of environment where it is expected to make profile measurements. An interferometer of Michelson or Mach-Zehnder type will be insensitive to external perturbations (i.e., low noise) if, and only if, both the reference and signal arms are subjected to identical perturbations or totally insulated from such perturbations. However, in the real world, both situations are hard to realize, mainly because of the fact that the reference and signal beams travel separate paths.

Minimizing their separation will lead to better signal-to-noise ratio; but, in most applications, the two beams are separated over several centimeters. This separation is mainly dictated by the need to access the surface to be profiled optically and the subsequent path matching condition to be met between the two arms. In the type of application that we anticipate for the DPI; viz., profiling the inside surface of magneto-plasma dynamic thrusters, the probing beam will have to be exposed to ambient environment if not to hostile environment. Even in a laboratory setup, a Michelson interferometer signal shows considerable drift unless elaborate precautions are taken against environmental perturbations. It takes a temperature differential of only 1.44°C between the two arms to generate random phase noises of the order of 2π when the two arms are separated by over 8 inches.

Figure 5 is a typical representation of the problem faced. The drift in amplifier output (zero at quadrature point) in the absence of any measurement is the result of phase noise. Since signal strength is much smaller than the noise level, elimination of random noise is essential to achieving sub-wavelength profiling capability. Suppression of noise through constant feedback, as is usually done in interferometry, is not possible in this situation since the random noise (<10 Hz) and the signal (pure dc) are in the same frequency regime. In situations where one cannot control the ambient perturbations and where feedback loops cannot be incorporated into the data acquisition system, the only way to eliminate or reduce the random phase noise is by subjecting both the reference and signal beams to the same perturbations. This can be achieved only when both arms travel the same path until the optical mixing occurs. A technique for achieving this is shown in Figure 6. The beam is split into object beam and reference beam at the lens. That part of the beam that gets through the hole in the lens acts as the reference beam whereas the portion that gets focused by the lens is the object or probing beam. The object beam, because of its small dimension, carries local phase information upon return from the surface whereas the reference beam wavefront returns with an average phase value which hardly undergoes any change as the beams are scanned across the surface (See Figure 7).

The returning beams interfere at a small but finite angle and, hence, closely spaced fringes are generated. For detection purposes, fringes will have to be projected, as shown in Figure 6.

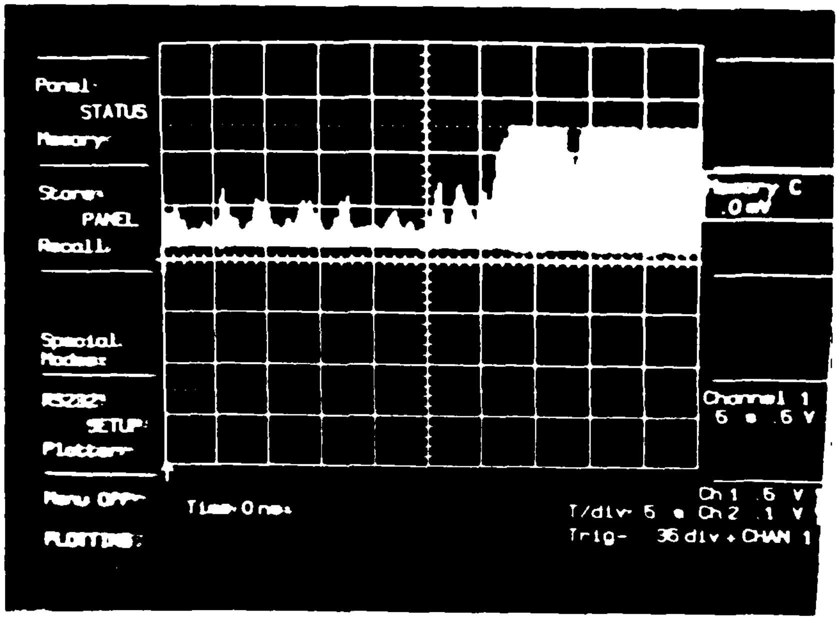


Figure 5. The CRT Display of Random Fluctuations in a Michelson's Interferometer Signal Resulting from Ambient Perturbation. Scales -5s/div., 1 V/div.

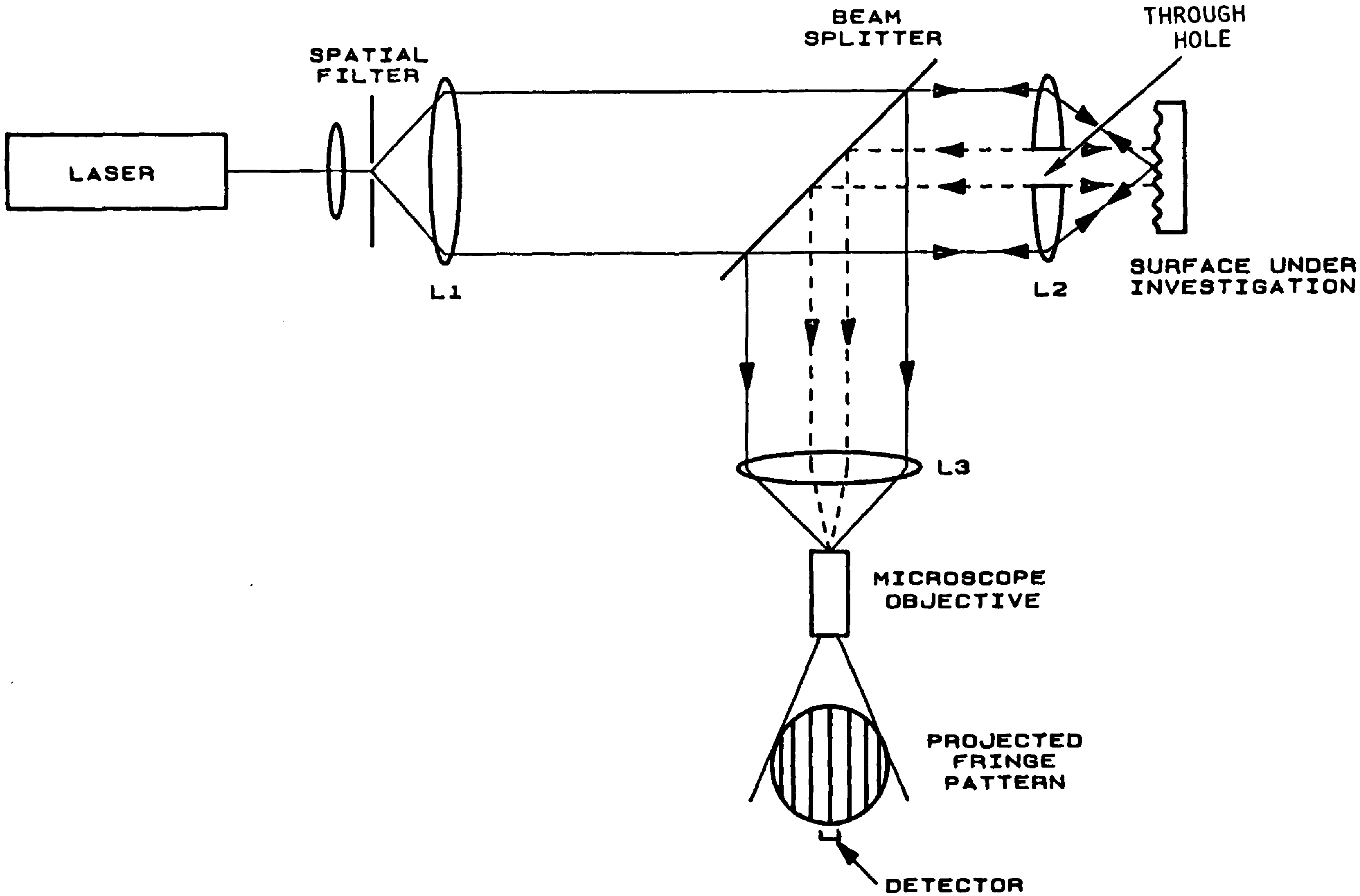


Figure 6. Schematic of the Single Beam Interferometer. In this Configuration, the Interferometer is inert to Ambient Perturbations.

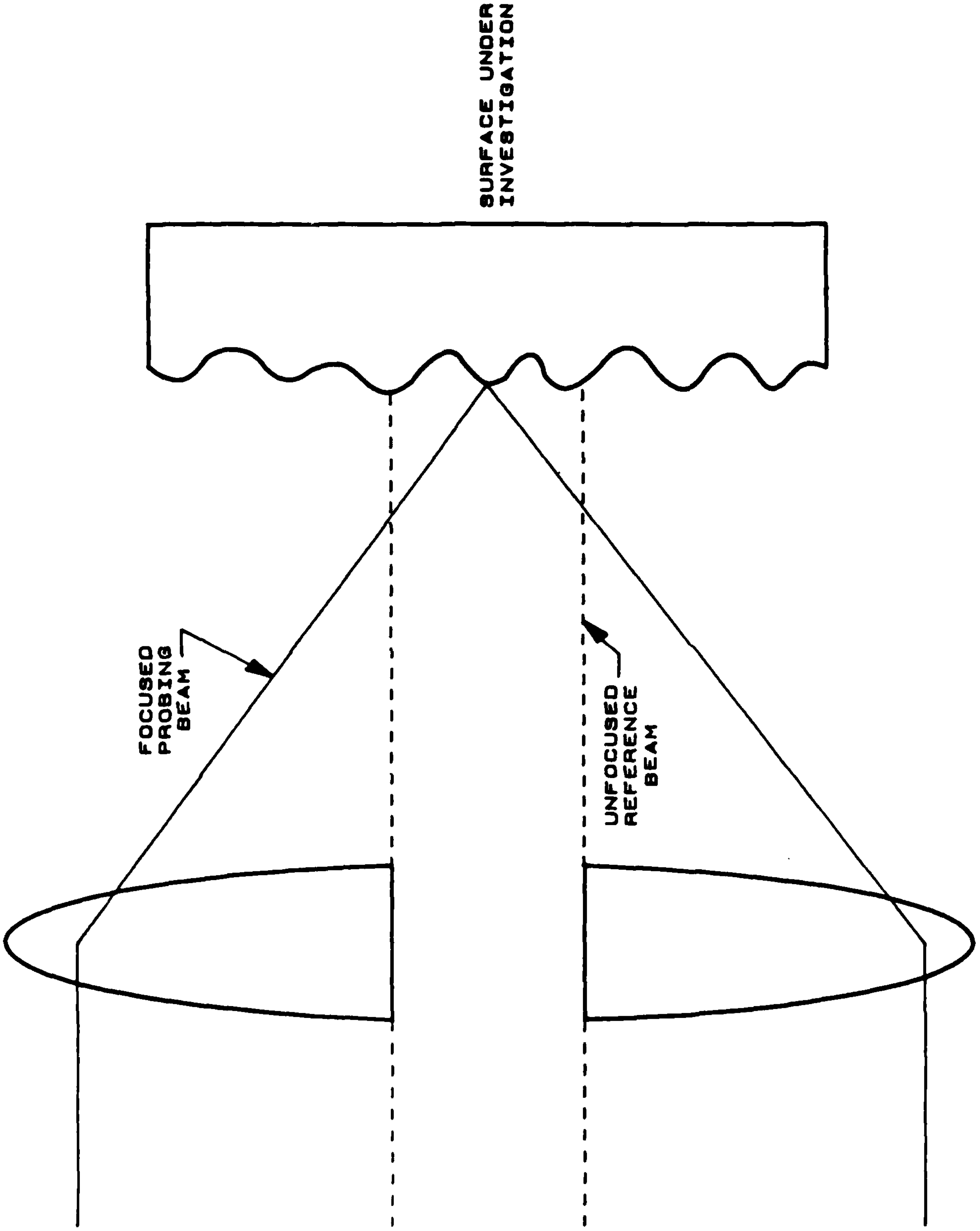


Figure 7. Geometry of the Reference Beam and Probing Beam on the Surface Under Test.

We have generated fringe systems both from a mirror as well as from an electrode surface. The fringe system generated is found to be very stable. The improvement in stability is at least two orders of magnitude (see Figure 8). Figure 9 shows the fringes from a mirror and those from the Cu electrode. The visibility of the latter is considerably reduced due to the speckle effect. Figure 10 shows the CRT display of the photomultiplier tube output looking at a fringe in the fringe pattern. The local intensity of the fringe pattern is given by the height of the top hat pattern. Variation in its height should correspond to change in the phase of the object beam since the output of the photomultiplier is given by

$$S = S_o \, [1 + \alpha \cos \phi]$$

where S_o is a constant that depends on the laser power, α is the visibility and ϕ the phase change occurring between the two beams. For small changes in ϕ, $d\phi$, caused by the surface features, this variation in detector output is

$$|dS| = S_o \, \alpha \sin \phi \, d\phi \, .$$

Under quadrature condition, i.e., $\phi = \pi/2$, the change in signal strength

$$dS \propto d\phi$$

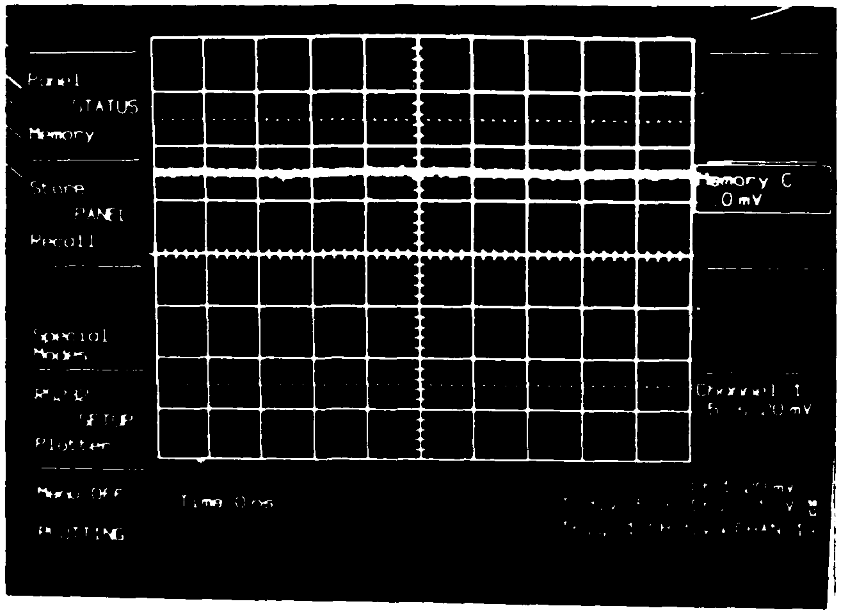
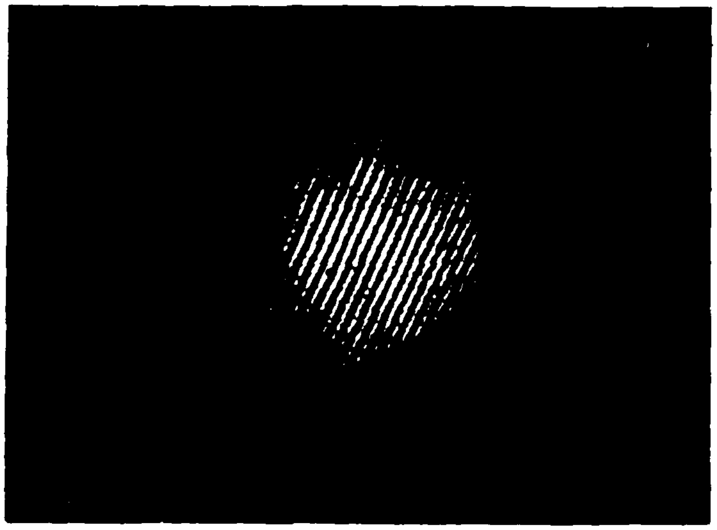


Figure 8. CRT Display of the Signal from the Common Path Interferometer. Scales-0.5 s/Div., 20 mV/div.

A)



B)

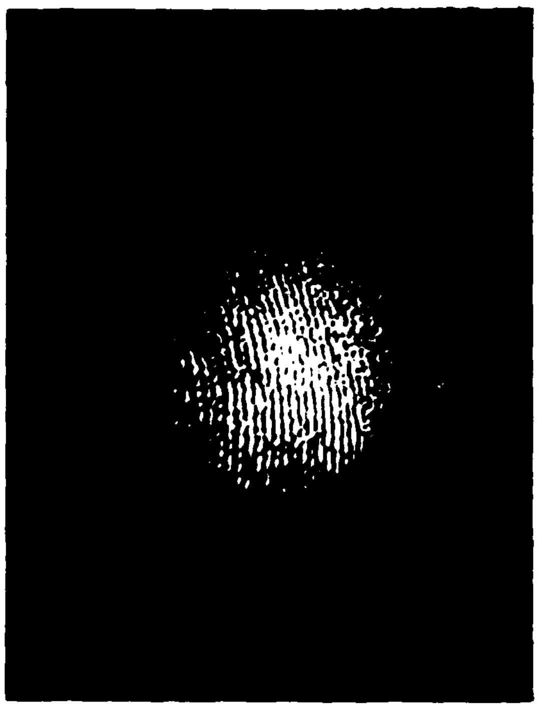
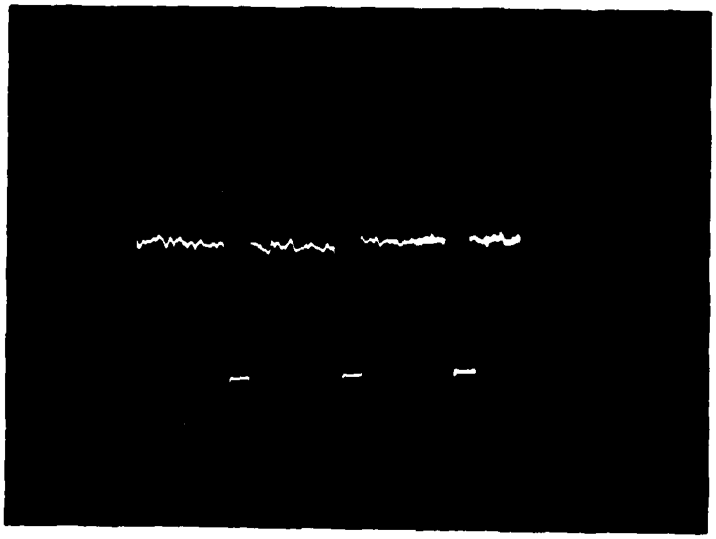


Figure 9. The Finite Fringe System Obtained using the Common Path Interferometer. A) From a Mirror B) From a Copper Electrode.

A)



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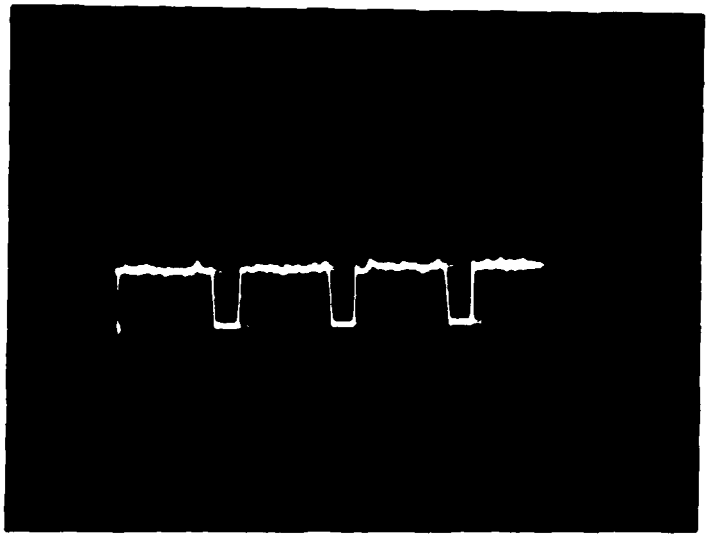

Figure 10. Traces A) and B) represent the PMT Output as Fringe Sweep past the Detector Pinhole.

Since there is no signal fading due to phase drift, signal processing is not difficult. With this arrangement, surface variations of the order of $\lambda/50$ can be measured without any elaborate data acquisition techniques or precautions against environmental perturbations. Figure 11 shows the profilometry done on a standard mirror using this interferometry. The detector used for the measurement was a photomultiplier tube and the signal was read off of a 50 MHz Tektronix scope. However, measurements have not been made from the surface of an eroded copper electrode. We plan to carry out these measurements in the immediate future and the result of the measurements will be reported in the next semi-annual report.

In spite of its excellent stability, the interferometer poses its own set of problems. Since the inner and outer beams interfere at an angle greater than 0°, the resulting interference generates a closely spaced finite fringe pattern and not an infinite fringe system. Since measurements have to be made using one fringe, the signal strength is considerably reduced and, hence, the need for a photomultiplier tube or a high gain detector. This could lead to a degradation of signal-to-noise ratio, thus affecting the attainable sensitivity.

Calibration of this interferometer is not as simple as that in a standard Michelson's interferometer since both the reference and object beams return from the same surface. Using special targets, however, calibration can be carried out. Another approach, instead of calibration, would be to check the performance of the interferometer against another established profilometer. In fact, the latter will be our first approach.

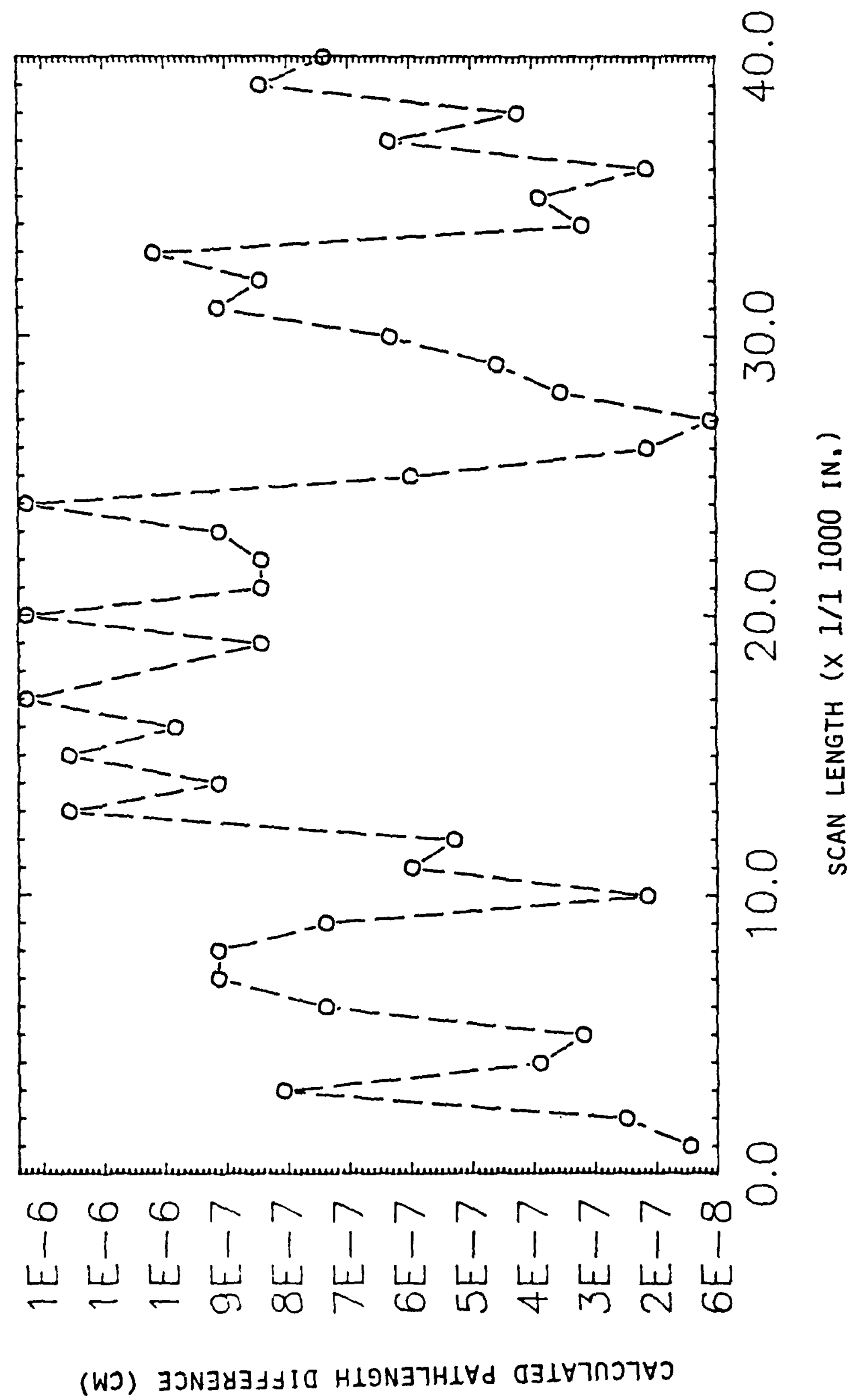

Figure 11. Plot of Surface Profile of a Standard Aluminum Mirror.

Since both the beams have the same polarization, electronic phase detection through heterodyning could not be carried out. However, it is possible to introduce frequency shifting by using appropriate phase retardation plates. Details of this technique and mathematical analysis of such a system will be given in the next report.

4.0 CONCLUSIONS

The conclusions based on results of the work done during the second year of this program are as follows:

1. Holographic Interferometry is not a viable technique for monitoring erosions in electrical propulsions under real test conditions.

2. Diffuse Point Interferometer must be modified from its original configuration to be able to make measurements under ambient perturbations.

3. The Modified Interferometer shows reduction in fringe drift by at least two orders of magnitude.

4. More work must be done to make the interferometer accessible to heterodyne detection which when achieved can increase its detection sensitivity.

5.0 REFERENCES

1. K. A. Arunkumar, M. Azzazy and J. D. Trolinger, "Optical Technique for the Measurement of High Temperature Material Erosion", Annual Report for the period March 85 - April 86. Submitted to AFOSR, Bolling Air Force Base, Washington DC, April 1986.

2a. N. Abramson, "Sandwich Hologram Interferometry: A New Dimension in Holographic Comparison", Applied Optics 13, p. 2019, 1976.

2b. N. Abramson, "Sandwich Hologram Interferometry 2: Some Practical Calibrations", Applied Optics., Vol. 14, p. 981, 1975.

6.0 TECHNICAL ARTICLE IN PREPARATION

"A Novel Approach to Common Path Interferometry," to be submitted to Applied Optics.

7.0 LIST OF PERSONNEL ASSOCIATED WITH THE PROGRAM

The scientists involved in this program are Dr. K. A. Arunkumar, Senior Scientist, Electro-Optics Group, and Dr. J. D. Trolinger, Spectron's Chief Scientist. The resumés of these individuals were furnished to AFOSR along with the first annual report.

8.0 PAPER PRESENTED AT MEETINGS, CONFERENCES, SEMINARS, ETC.

The results of our work had not been reported in any meeting.

9.0 NEW DISCOVERIES, INVENTIONS OR PATENT DISCLOSURES AT SPECIFIC APPLICATION STEMMING FROM THE RESEARCH EFFORT

The newly developed DIP interferometer can be applied to surface measurements where high accuracy is needed. We are looking at the possibility of patenting this interferometer.

9.1 Highlights of the Common Path Interferometer

This interferometer without heterodyning and without any isolation from ambient perturbations is found to be capable of detecting surface features of the order of tens of angstroms. With the introduction of heterodyning and improved detection electronics, we feel its sensitivity can be pushed to angstrom level.

The common beam path provides remarkable fringe stability and makes the interferometer ideally suited for field and production line measurments. Hence, we anticipate potential applications for this interferometry in many scientific and industrial realms.

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